Hydrology and Hydraulic Analysis of Nasiri Flash Flood Disaster Event on the 1st August 2012

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ABSTRACT

Nasiri lays in the Luhu village, Huamual district, West Seram Regency, Maluku province. Nasiri experienced in flash flood on August 1st, 2012 which had never happened before. There was no rainfall station and water level recorder at that time. It is rather difficult to find out the cause and yet Nasiri River was only 8 meters wide. The research started with identifying base flow, soil characteristics, learning flood video record, routing the river reach, finding the nearest rainfall station, and also interviewing some peoples there. Field data area was complemented with satellite radars. AutoCAD 2007, IFAS 2.0.1.2, Geostudio 2004, ArcGIS 10.2, HEC-HMS 4.2.1, and HEC-RAS 5.0.3 were used to perform simulations of the natural river with and without precipitation calibration, and also with and without landslide dam in the river. HEC-RAS was subject to perform 2 (two) dimensional flood routing. The result was fairly satisfying. Nasiri watershed was experiencing in flash flood caused by 2 (two) landslide dams which collapsed in 2 (two) different times. The first landslide dam was 7.55 meters high which collapsed at 09:52 (UTC+9) with 83.58 m3/s of peak discharge. The second landslide dam was 8.91 meters high which collapsed at 14:24 (UTC+9) with 54.16 m^3/s of peak discharge.

Keywords: Nasiri, flood, landslide dam, two-dimensional routing.

1 FLOODS AND LANDSLIDES

Floods and landslides are the most frequent disasters in Indonesia. Based on data and information from National Disaster Management Agency (BNPB, 2017), recorded 1,481 times of disaster from January to July 2017. Flood and landslide disaster has contributed 3.17% of total disaster incidents with locations spread throughout Indonesia. It caused 19 people died and disappeared, 37 people were injured, 163 houses were severely damaged, 4,438 houses were slightly damaged, and 105,768 people suffered and displaced. Given the significant number of victims, research on these disasters is indispensable as a mitigation effort.

2 RESEARCH METHOD

2.1 Nasiri Location

Nasiri is located on a peninsula that has a land width of ±5 km. Geographically, Nasiri lies at 3º20'25.80"-3º20'37.18" S and 127º56'14.22" - 127º56'27.62" E. Nasiri is a small village with the length of east-west ±500 meters and long north-south ±300 meters. Hamlet of Lirang in the north, the hamlet of Talaga Kambelu in the west, and to the east by the hills (Figure 1).

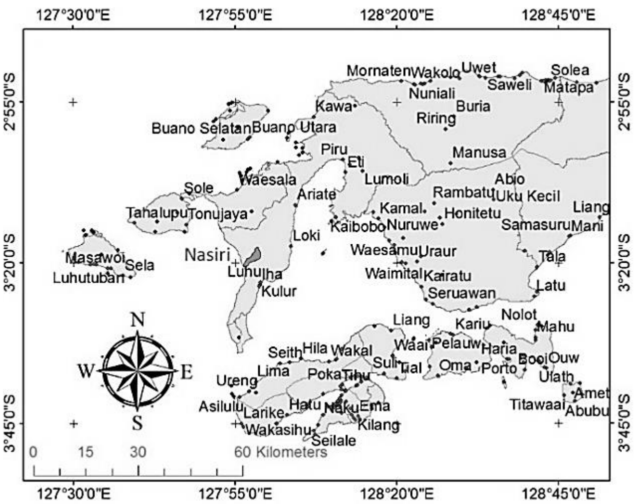

Figure 1. Nasiri's location.

Nasiri was flash flooded on August 1st, 2012. It was the only flood that ever happened, and yet this paper was going to analyze the flash flood event chronologically.

2.2 Research Flow Chart

Because there were so many variables in this research, a simple flow chart was drawn for analysis as shown in Figure 2.

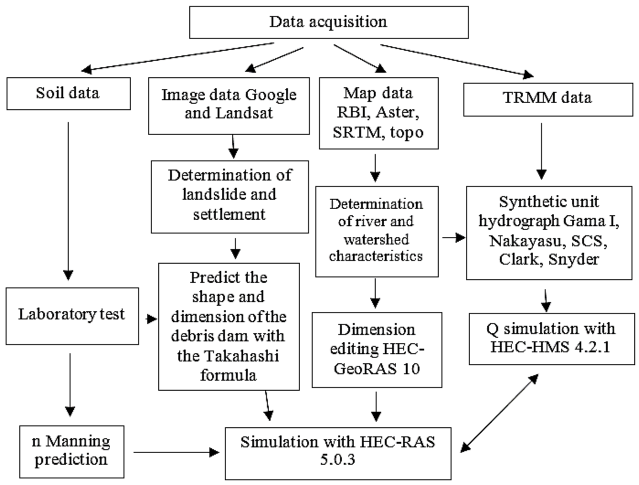

Figure 2. Research flowchart.

2.3 Soil Investigation

Some samples of soil were tested in the Universitas Gadjah Mada laboratory. Those samples were taken from several places in Nasiri as shown in Figure 3. Sieve analysis showed that the soil contains 70% of sand. The most appropriate Soil Conservation Service-Curve Number (SCS-CN) classification is B (after Nearing et al., (1996)).

The composite value for CN B in Nasiri is 59.457. The result from the laboratory is listed in Table 1.

Table 1. Manning's *n* value prediction

Method	Sample 1	Sample 2
Strickler **(1923)**	0.046	0.046
MPM (1948)	0.054	0.057
Julien **(2002)**	0.074; 0.058; 0.054	0.073; 0.062; 0.056

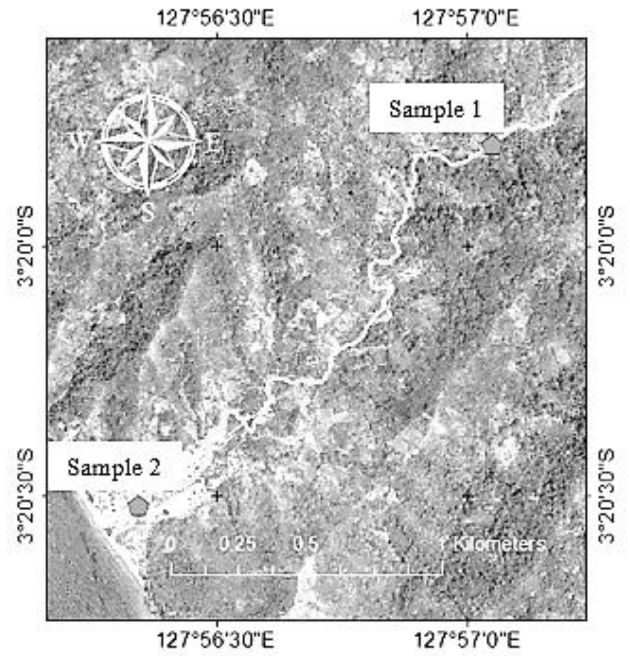

Figure 3. Soil samples data acquisition place.

2.4 Satellite Images

Google satellites recorded an avalanche and river flow path in the upstream of Nasiri. It lied ±1.5 km from the people settlements at the altitude of +53 meters above sea level (MASL). Figure 4 shows the evidence of an avalanche on the river bank, while Figure 5 presents 3 (three) locations that allegedly occurred landslide. Landsat images could not display clearly because of its 30×30 meters resolution.

Figure 4. Image from the Google satellite on October 8th, 2012.

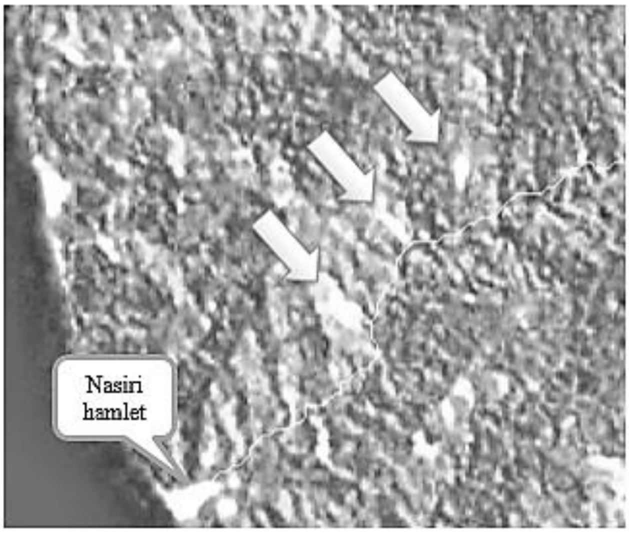

Figure 5. Image from ArcGIS online imagery.

3 DIGITAL SURFACE MODELS (DSM) AND DIGITAL TERRAIN MODELS (DTM) COMPARISON

ASTER (1 arc-second), SRTM (1 arc-second), and RBI (Indonesian Topographical Map with 25 meters of contour interval) were compared to the ground survey mapping (see Figure 6, Figure 7 and Figure 8). By means of Nash-Sutcliffe (1970) index, the comparison result is shown in Table 2. Choosing the GPS-TOPO map was more accurate for river reach, while SRTM was useful for watershed elevation. ArcHydro version 2 was used to create watershed delineation and river reach confluence. To improve the accuracy of river reach elevations and population settlements, the authors added 2,500 points based on documentation and tracing on the ground to obtain Digital Elevation Models (DEM) with a resolution of 1 x 1 meter.

Table 2. Nash-Sutcliffe index of Digital Surface Models (DSM)/Digital Terrain Models (DTM) elevation

ASTER	SRTM	RBI	GPS-TOPO
-1.618	0.703	0.322	0.938

Table 3. Watershed characteristics comparison

Parameter	ASTER	SRTM	RBI
Area (km^2)	10.523	10.551	10.492
River length (km)	7.965	8.201	7.902
River slope (m/m)	0.092	0.089	0.105
River confluence	20	21	45
Min. elev. (m)	0	8	3.694
Max. elev. (m)	916	931	903.673

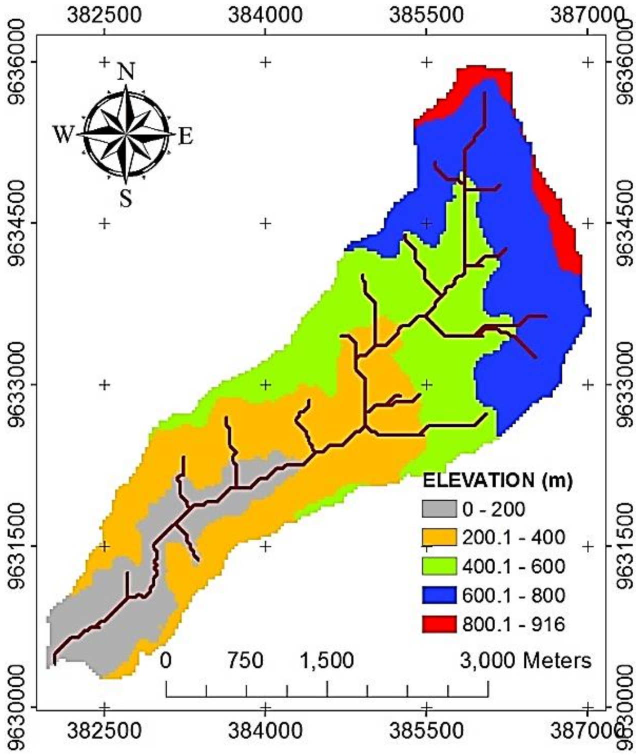

Figure 6. ASTER watershed (2011)

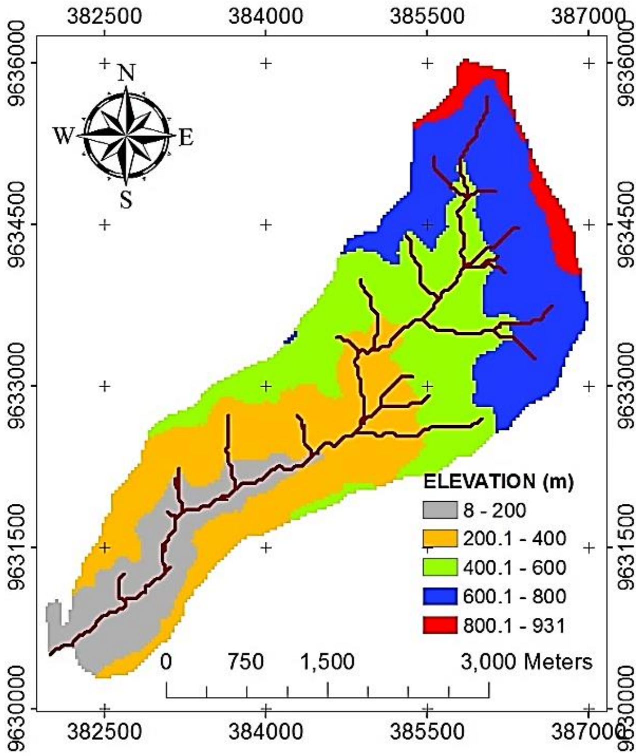

Figure 7. SRTM watershed (2014)

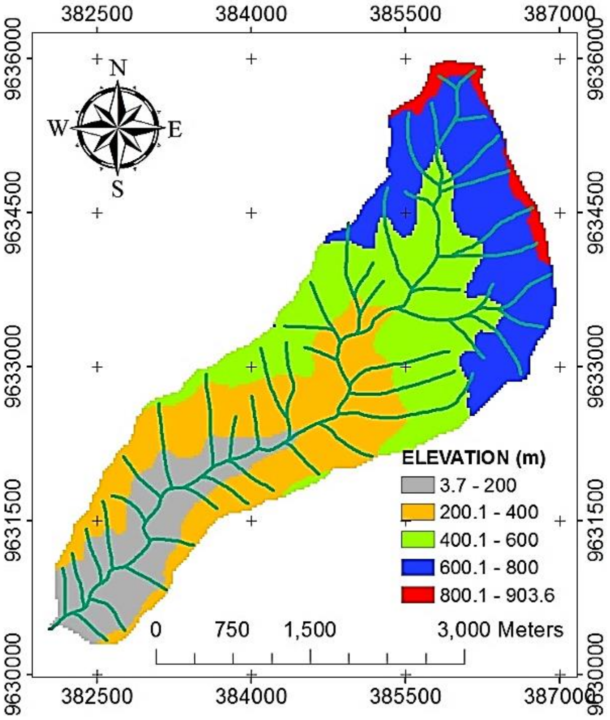

Figure 8. RBI watershed (2009).

4 RESULTS AND DISCUSSIONS

4.1 Landslide Dam Dimension Prediction

The dimensions of landslide dams were predicted with an empirical model of Takahashi (2007), as presented by Equation 1 to Equation 4 and Figure 9.

$$L_B = \frac{W}{\cos\theta} + \frac{V\cos\theta}{2BW}K \tag{1}$$

$$L_T = \frac{W}{\cos\theta} - \frac{V\cos\theta}{2BW}K \tag{2}$$

$$K = \frac{\cos\theta}{\tan(\varphi+\theta)} + \sin\theta + \frac{\sin(90^\circ+\varphi)}{\sin(\varphi-\theta)} \tag{3}$$

$$D_{\max} = \frac{2V}{B(L_B + L_T)} \tag{4}$$

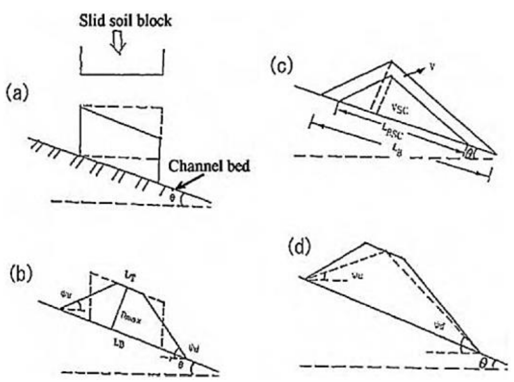

Figure 9. Landslide dam transformation (Takahashi, 2007)

Preliminary prediction of landslide dam dimension is presented in Table 4. The value will be tested in the HEC-RAS simulation, while the prediction of landslide location that forms the natural dam is presented in Figure 10.

Table 4. Landslide dam dimension prediction

Parameters	Dimension Up (3)	Middle (2)	Bottom (1)
L_T (m)	24.60	0.02	27.26
L_B (m)	75.53	26.70	49.75
D_{max} (m)	16.98	8.96	7.55
θ (°)	0.53	0.69	0.86
ψ_u (°)	-0.10	-0.09	-0.56
ψ_d (°)	0.95	1.27	1.15
Elev. (MASL)	+101.87	+78.53	+53.23

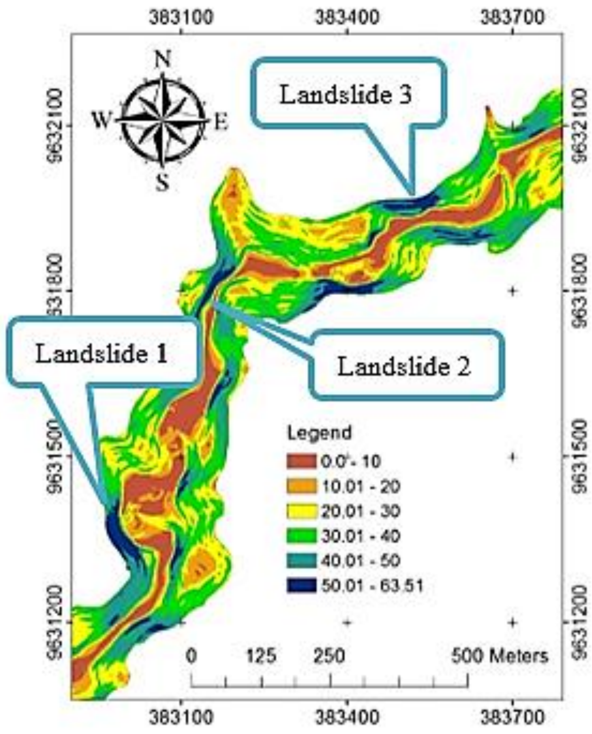

Figure 10. Slope (°) and landslide dam location.

4.2 Landslide Dam Stability Factor

The dimensions of landslide dams were tested for stability with GEOSTUDIO 2004. Material models were using Mohr-Coulomb (Parry, 2004). The results are displayed in Figure 11, Figure 12, Figure 13, and Table 5.

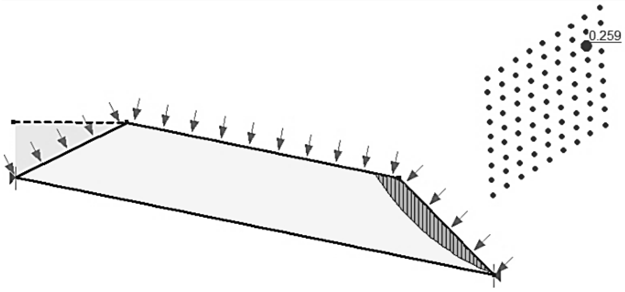

Figure 11. Landslide 1 model.

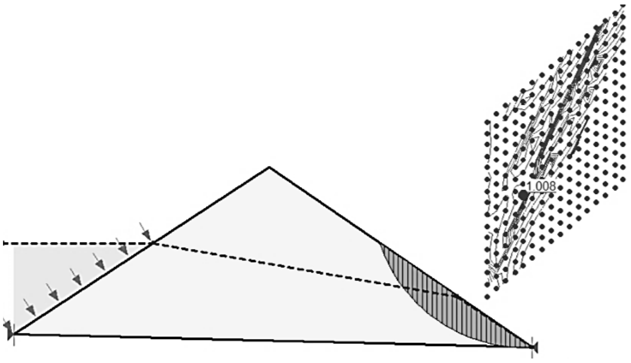

Figure 12. Landslide 2 model.

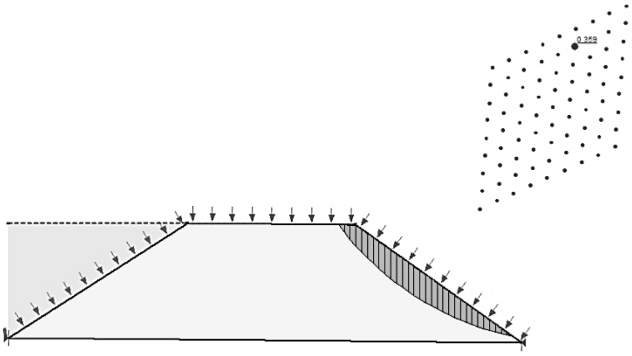

Figure 13. Landslide 3 model.

Table 5. Failure type of each landslide model

Landslide	1	2	3
Elev. invert (m)	+53.23	+78.53	+101.87
Shape	trapezoidal	triangle	trapezoidal
Failure type	overtopping	piping	overtopping
Elev. failure (m)	+60.78	+85.95	+123.89

4.3 Nasri's Resident Documentary

A resident was documenting the flood events with his phone video camera. It was a very rough video, but it could illustrate the magnitude of the flood (Hidayatulloh, 2017). From Figure 14 it appeared that flood flow was very fast (± 5.4 m/s) and muddy, swept away trees, and have destroyed many houses. Predicted discharge is 54.16 m^3/s at 14:38 PM (UTC+9).

Figure 14. A captured image from video recording during the flood (Hidayatulloh, 2017).

Flood modeling which was done with HEC-RAS and HEC-HMS would be adjusted with oral information obtained on 13-20 July 2014 from several Nasiri residents. Resume of oral information is shown in Table 6.

Table 6. Nasiri resident oral information

Date	Information
7/27-7/29/2012	There was no landslide in river reach.
7/31/2012	The rain started in the afternoon and lasted continuously until the evening.
8/1/2012	The rain still lasts until night. There was a flash flood at 10:00 AM (UTC+9). The turbid flood waters carry trunks of trees, mud, and rocks. The riverbed changed direction and crashed 61 buildings to shreds. The flood waters receded for several hours but rose again in the afternoon. Toward late at night, the river water has subsided to normal.
8/2-4/2012	The weather was sunny and reportedly no rain. The river water gradually changes its turbidity level to normal again.

4.4 Precipitation Data

The most popular satellite precipitation data in Indonesia is Tropical Rainfall Measuring Mission (TRMM) 3B42RT version 7. In Maluku Province, the monthly data correlation was 0.78 and looks underestimate when compared to ground rainfall data (Mamenun, et al., 2014). In Lohiatala, a rainfall station which lies ±43 km from Nasiri, TRMM was still underestimated at main rainfall months (July-August). TRMM recorded only 88% of total precipitation amount. While in Patimura, a rainfall station which lies ±44 km from Nasiri, TRMM has a good monthly correlation of 0.95.

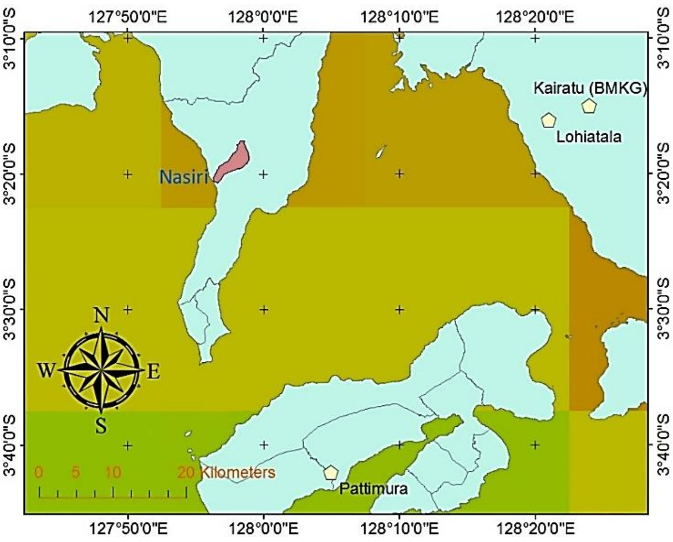

Figure 15. Tropical Rainfall Measuring Mission (TRMM) grid compares to rainfall station position.

Table 7. Tropical Rainfall Measuring Mission (TRMM) precipitation data

Date (WIT)	TRMM 3B42RT v.7 (mm)	Calibrated (mm)
19-Jul-12	1.3363	1.5056
20-Jul-12	117.3647	132.2320
21-Jul-12	1.0137	1.1421
22-Jul-12	8.3404	9.3969
23-Jul-12	0.0000	0.0000
24-Jul-12	0.0461	0.0519
25-Jul-12	0.0000	0.0000
26-Jul-12	0.0000	0.0000
27-Jul-12	0.0000	0.0000
28-Jul-12	0.4147	0.4672
29-Jul-12	0.0000	0.0000
30-Jul-12	1.0137	1.1421
31-Jul-12	55.9406	63.0269
1-Aug-12	199.3790	224.6355
2-Aug-12	12.1467	13.6854
3-Aug-12	0.0000	0.0000
4-Aug-12	0.0000	0.0000

According to the rainfall data in Patimura station, the highest rainfall was recorded at 263 mm on June 28th, 2007. The highest rainfall in the Lohiatala station was 372 mm on January 2nd, 2009. The highest rain sequence ever in the Nasiri basin, based on the 1998-2014 data, can be seen in Table 8.

The precipitation that occurred on August 1st, 2012 was in the fourth rank. While on August 4th, 2010, there was no flood in Nasiri. In contrary, on June 8th, 2012 there was no flood recorded. The results implied that rainfall was not the main factor as the cause of flood incident on August 1st, 2012.

Table 8. Highest precipitation in Nasiri (TRMM)

No	Date (UTC)	Intensity (mm/hour)
1	2010:08:04	226
2	2010:06:16	183
3	2011:06:05	174
4	2012:08:01	141
5	2012:06:08	137
6	2008:08:04	137
7	2011:05:19	127
8	2004:02:18	119
9	1999:07:03	113
10	2012:07:31	113

4.5 Natural River Flow Hydrograph

Five synthetic unit hydrographs (SUHs) were compared to view the peak flood at 10:00 AM on August 1st, 2012. HEC-HMS simulation result without landslide dam is shown in Table 9 and Figure 16.

Table 9. Peak flow from synthetic unit hydrographs (SUHs)

SUH	Peak flow (m^3/s)	Time (UTC+9)
Gama I (Sri Harto, 1985)	36.587	09:24
Nakayasu (1951)	40.206	09:00
SCS (Snider, 1972)	42.032	09:20
Snyder (1938)	43.192	09:04
Clark (1945)	43.273	09:06

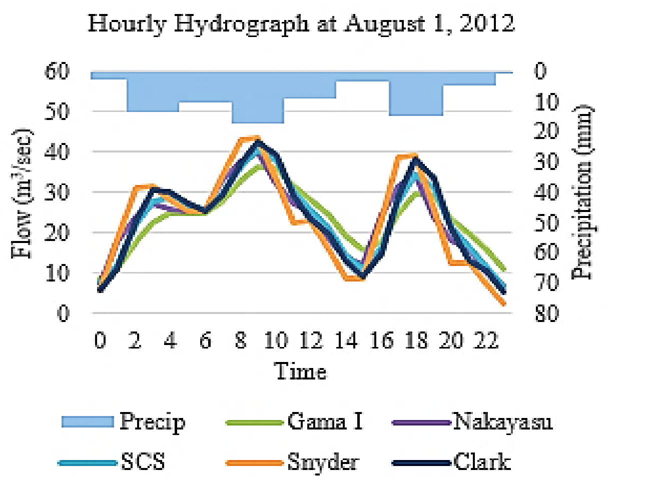

Figure 16. Hourly hydrographs on August 1st, 2012

There are differences between SUHs in Figure 16 and Table 6. Peak flow was occurred at 09:00 till 09:24, while Nasiri's residents said that the flood hit at 10:00. Approximated peak flow was more than 60 m^3/s, while Figure 16 shows different results. There must be two landslides in the river upstream. The first was before 10:00 AM and the second was before 14:38 PM.

4.6 Calibrating Manning Roughness Coefficients

Several n values from Table 1 were simulated in HEC-RAS 5.0.3. Full momentum equations were applied in this case as listed in Equation 5 and Equation 6 (Brunner, 2016).

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-g\frac{\partial H}{\partial x}+v_t\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)-c_f u+fv \quad (5)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial u}{\partial y}=-g\frac{\partial H}{\partial y}+v_t\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)-c_f v+fu \quad (6)$$

Table 10. Index of Nash-Sutcliffe (η) for Flood Plain

n Manning	0.046	0.056	0.057	0.062	0.073
Index **(η)**	0.454	0.977	0.995	0.943	0.638

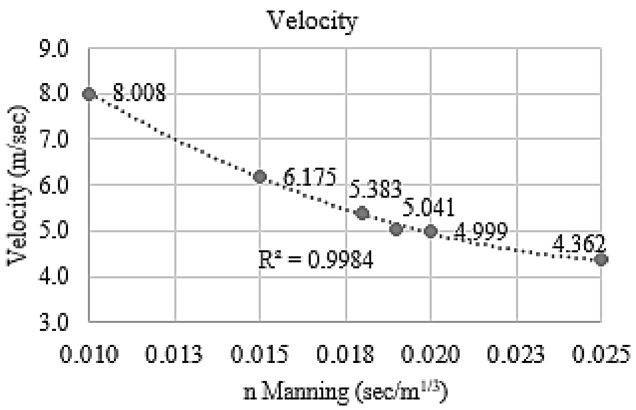

Figure 17. Rating curve for velocity.

From some of the Manning n values, it can be calculated the ideal value for settlements and river channel by rating curves (Figure 17). From Table 10, the value of n = 0.057 (MPM, 1948) resulted in the best and the maximum debit at 10:00 (UTC+9), i.e. 83.58 m^3/s. As for the Manning n value of the river channel corresponding to the information in Section 9 was 0.018, which resulted in a velocity of 5.4 m/s.

4.7 Compatibility of Runoff Volume

Flood analysis from July 19th, 2012 to August 4th, 2012 obtained a predicted volume of 4,538,304 m^3. The calculated results from several Ia-CN values are listed in Table 11. The ideal value of Ia-CN is listed in Table 12.

Table 11. Ideal value of Ia-CN for Nasiri

Ia	0.05	0.10	0.15
CN	65.838	67.428	68.831

4.8 Time of the First Landslide

Four locations were set as calibration points (Figure 18). The four calibration points had the value of flow depth at peak flood as shown in Table 13. The entire HEC-RAS simulation was performed over 36,800 cells measuring 3×3 meters and at 0.3 second calculation time interval.

Table 12. Flow depth at peak flood

No	Location	Depth
1	School	1.0 meter
2	House 1	0.8 meter
3	House 2	0.7 meter
4	Mosque	0.5 meter

Table 13. Runoff volume comparison from standard and calibrated precipitation (×1000 m^3)

CN	Ia = 0.05		Ia = 0.10		Ia = 0.15		Ia = 0.20	
	standard	calibrated	standard	calibrated	standard	calibrated	standard	calibrated
45	3203.8	3626.9	3076.1	3494.9	2950.0	3364.1	2825.6	3234.6
50	3421.8	3866.2	3311.5	3752.9	3202.1	3640.3	3093.7	3528.5
55	3629.7	4091.9	3535.5	3995.6	3441.7	3899.7	3348.5	3804.3
60	3828.0	4304.9	3748.6	4224.1	3669.3	4143.5	3590.4	4063.1
65	4017.5	4506.3	3951.5	4439.5	3885.6	4372.8	3757.4	4242.9
70	4198.6	4697.1	4144.9	4642.9	4091.3	4588.8	4037.8	4534.8

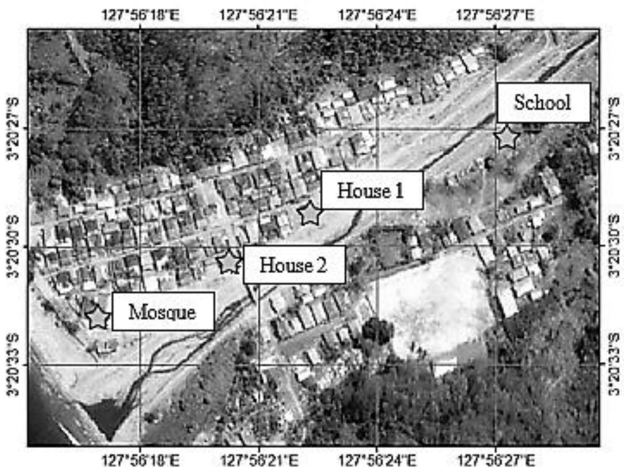

Figure 18. Calibration points.

According to Table 14 and Table 15, it can be concluded that there was an avalanche in the river channel at an elevation of +53.23 MASL as high as 7.55 meters at 09:40 and began to collapse at 09:52. The most appropriate breach formula is Von Thun and Gillette (1990) (see also Figure 19).

4.9 Time for the Second Landslide

Analog by way of the first landslide was calculated, then the calculation for flood at 14:38 was also performed. The central landslide as high as 8.96 meters at the +78.53 MASL elevation was simulated in HEC-RAS. From the HEC-HMS simulation without a landslide dam, the Nasiri River only supplies 16 – 20 m^3/s of discharge at 14:00 – 15:00. In contrast to the lower landslides seen quite clearly from Google Earth imagery, the central landslide was not clearly visible from satellite imagery. So it takes several times experiment of the dimension of the middle landslide. The experiment of the landslide dimension should refer to the potential avalanche area seen from ArcGIS imagery online imagery.

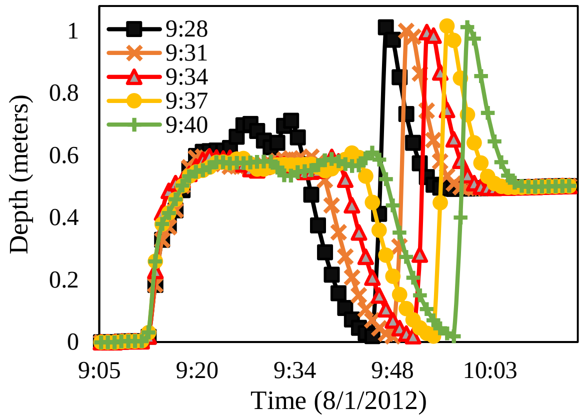

Figure 19. Flow depth at school caused by landslide dam (1) from 09:28 to 09:40 with Von Thun and Gillette (1990) breach formula.

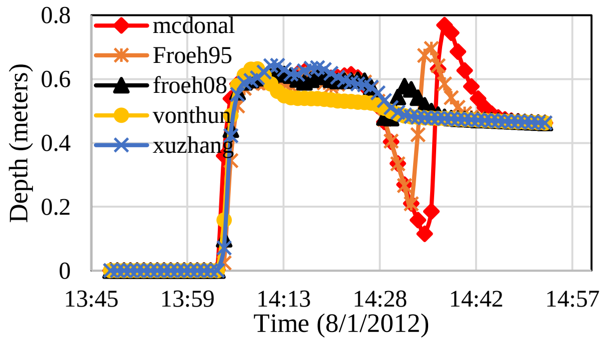

Figure 20. Flow depth at school caused by landslide dam (2).

Table 14. Flow depth caused by landslide dam (1) (meter)

Formula	Time	School	House 1	House 2	Mosque	Velocity (m/sec)
McDonald and Monopolis (1984)	9:33	0.870	0.848	0.583	0.332	3.075
Froehlich (1995)	9:37	0.930	0.903	0.603	0.349	3.214
Froehlich (2008)	9:37	0.965	0.899	0.598	0.353	3.273
Von Thun and Gillette (1990)	9:40	1.001	0.925	0.649	0.362	3.269
Xu & Zhang (2009)	9:37	0.921	0.895	0.575	0.349	3.175

Table 15. Index η from landslide dam (1)

Formula	McDonald (1984)	Froehlich (1995)	Froehlich (2008)	Von Thun (1990)	Xu & Zhang (2009)
Index η	0.531	0.631	0.670	0.714	0.587

Table 16. Dimension prediction of landslide dam (2)

Parameters	1	2	3	4	5
L_T (m)	0.02	0.09	0.23	0.36	0.50
L_B (m)	26.70	26.61	26.48	26.34	26.20
D_{max} (m)	8.96	8.91	8.82	8.73	8.64
θ (°)	0.69	0.69	0.69	0.69	0.69
ψ_u (°)	-0.09	-0.09	-0.09	-0.10	-0.10
ψ_d (°)	1.27	1.27	1.27	1.27	1.27
River invert (m)	+78.5	+78.5	+78.5	+78.5	+78.5

Table 18 shows that there was an avalanche in the river channel at +78.53 MASL elevation as high as 8.91 meters at 14:19 and began to collapse at 14:24. The flood hazard map from the HEC-RAS simulation could be seen in Figure 21.

Table 17. Flood depth from the second avalanche

Height (m)	Time	School	House 1	House 2	Mosque	Velocity (m/s)
8.96	14:18	0.768	0.790	0.516	0.313	2.509
8.91	14:19	0.753	0.748	0.475	0.302	3.048
8.82	14:19	0.741	0.746	0.463	0.296	3.025
8.73	14:19	0.741	0.744	0.463	0.296	3.025
8.64	14:19	0.728	0.737	0.454	0.292	3.006

Table 18. Index η for landslide dam (2)

Height (meters)	8.96	8.91	8.82	8.73	8.64
Index η	0.970	0.999	0.998	0.998	0.993

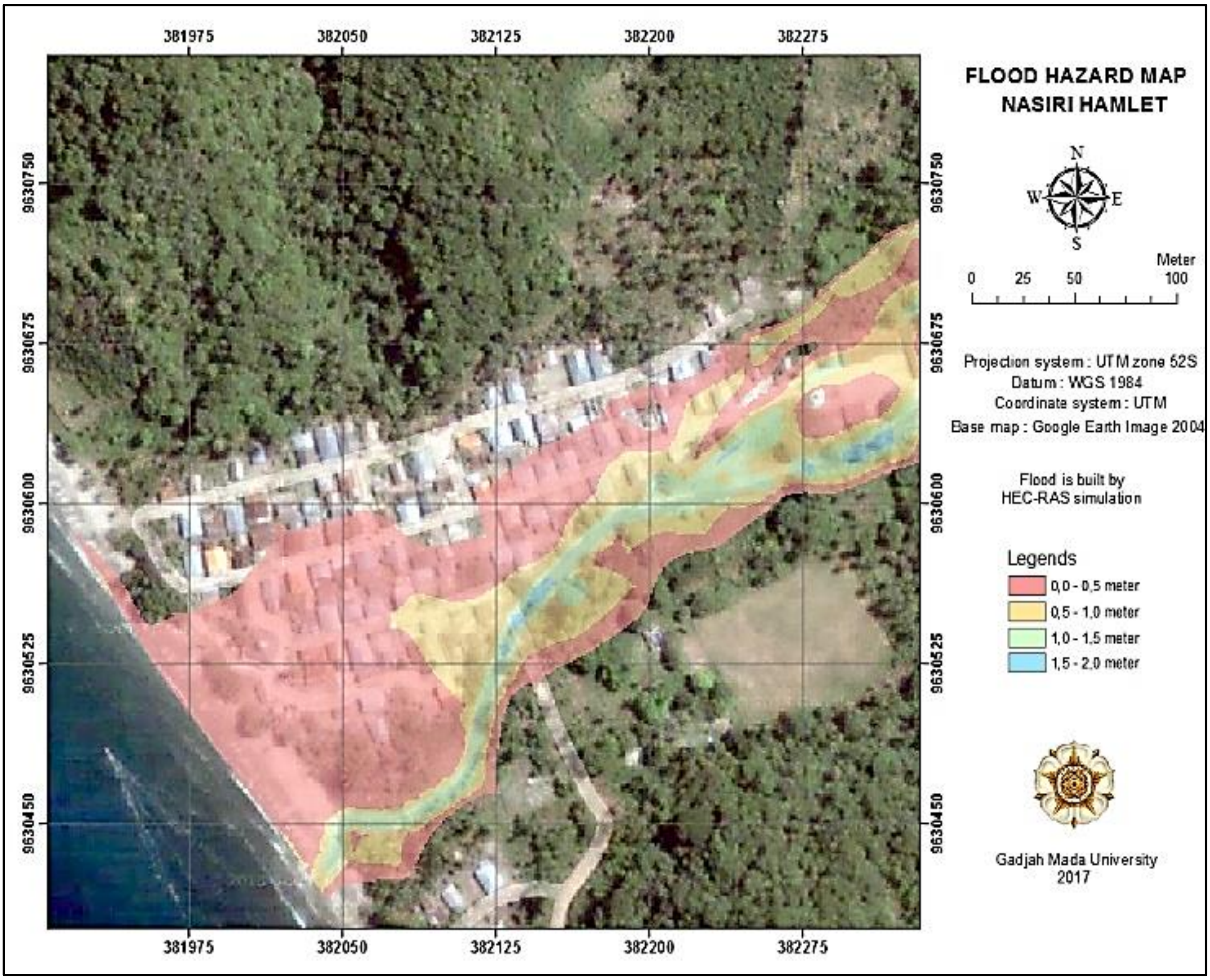

Figure 21. Flood hazard map at Nasiri.

5 CONCLUSIONS

Only 46 houses, or about 47% of the total settlements area, were free from floods. The chronological flow of flood events in Nasiri watershed is as follows.

July 31st, 2012 at 17:00, it started to rain in the afternoon.

August 1st, 2012

09:40 First landslide dam formed at +53.23 MASL elevation as high as 7.55 meters.

09:52 First landslide dam collapsed.

10:00 First flood came into the settlements and destroyed 61 houses. Peak discharge was 83.58 m^3/sec.

14:19 Second landslide dam formed at +78.53 MASL elevation as high as 8.91 meters.

14:24 Second landslide dam collapsed.

14:38 Second flood came into the settlements. Peak discharge is 54.16 m^3/sec.

21:00 Rain stopped and the flow began to recede.

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